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Abstract

We study the influence of energy endowments on the location of energy-intensive industries. We use data on manufacturing sectors in 50 US states from 2002 until 2008, with detailed information on state endowments of coal, natural gas, oil and hydropower and sectoral fuel and electricity intensities. The effect of energy on industry location is statistically and economically significant. A one standard deviation increase in energy endowments per capita increases the activity of energy-intensive industries by about 20%.

JEL-Classification: F10, R12
Keywords: industry location, factor endowments, energy, Heckscher-Ohlin model

1 Introduction

The Heckscher-Ohlin model is regarded as the workhorse model for international trade. It links industry location and trade to production factor endowments. Each region attracts industries that require its abundant factors, and trade primarily ensues between regions with dissimilar factor endowments. The model is celebrated by theorists, but its empirical merits were initially subject to debate. Subsequent work has shown however that the H-O model does remarkably well in explaining industry location and the factor content of trade when relaxing some of its rigorous assumptions. Whereas the model is traditionally applied to

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international data, a recent literature has recognized its potential for studying the patterns of intranational and regional specialization. This paper seeks to contribute by focussing on the effects of energy endowments on intranational industry location. Though it has not received much attention in empirical tests of the H-O model, energy is a potentially important driver for industry location. The variation in regional endowments as well sectoral intensities is much higher for energy than for capital and labour [Gerlagh and Mathys, 2010]. Using highly disaggregated data on US states, we find that endowments of coal, natural gas, oil and hydro significantly affect the location of energy-intensive industries.

1.1 Energy

In spite of the large literature on factor endowments and the pattern of trade and industry location, few papers have analyzed the role of energy in detail. Hillman and Bullard [1978] consider the comparative advantage of the U.S under the assumption of capital-energy complementarity. Though they lack credible capital data, they speculate that the U.S. may have a comparative advantage in both capital and labour, in contrast to previous findings on the Leontief Paradox. Ellison and Glaeser [1999] include electricity, natural gas and coal in a list of 20 sources of comparative advantage to explain the location of industry within US states. Energy-intensive industries are overrepresented in states with low energy prices, though energy prices are potentially endogenous. Finally, in a paper close to ours, Gerlagh and Mathys [2010] focus on the impact of energy abundance on industry location in 14 OECD countries. Energy abundant countries tend to be net exporters of embodied energy and attract more energy-intensive industries.

Energy can be an important driver of geographic specialization for several reasons. After labour and capital, it is the most important factor of production. While its share in value added in U.S. manufacturing may seem small in absolute terms at 4% [Berndt and Wood, 1975], it is comparable to the share of capital expenditures, which is around 6.5%[1]. Furthermore, sectoral intensities as well as state endowments vary much more for energy than for capital and skilled labour. Factor intensities for 6 digit NAICS manufacturing sectors are depicted on a logarithmic scale in Figure 1. We take the average wage per worker as a proxy for skill intensity. The variation in sectoral energy intensities is more than 3 times as large as the variation in capital intensities. A similar picture emerges when comparing energy and skill intensities, though the variation in wages is obviously bounded.

[1] Source: Annual Survey of Manufactures, US Census

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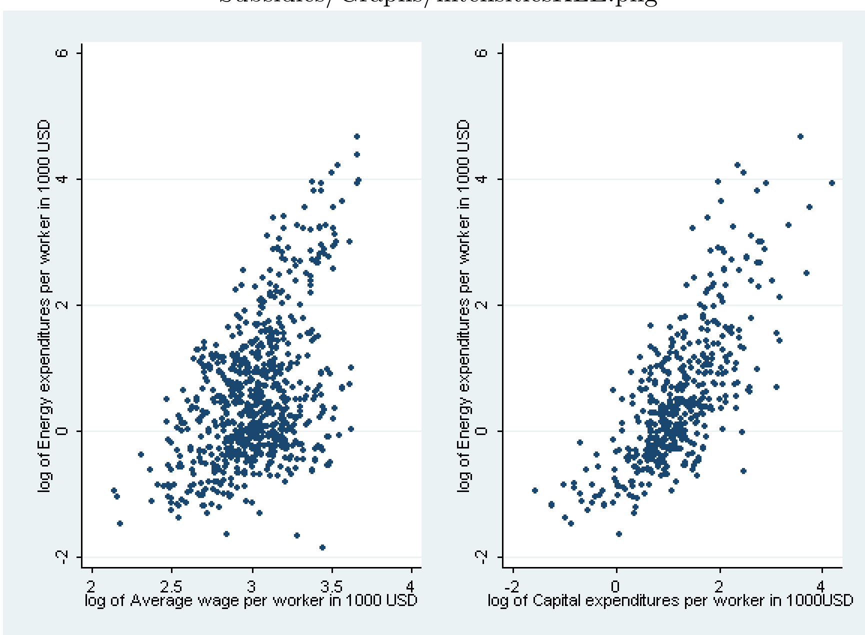

Figure 1: Labour, capital and energy intensities in US 6-digit manufacturing sectors. (Source: Economic Census, 2007)

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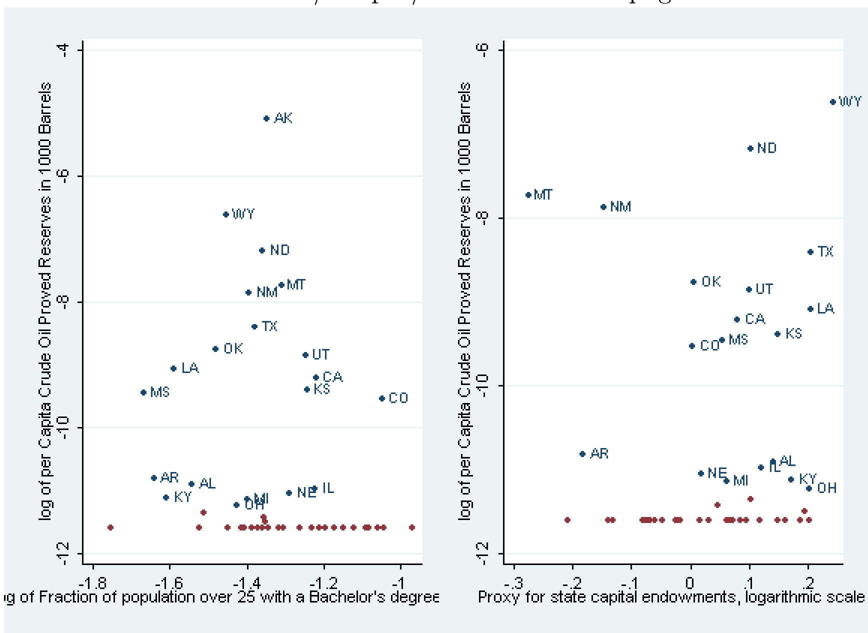

Figure 2: Oil, capital and skilled labour endowments of US states (Source: EIA and Economic Census, 2007). Red dots represent states with little or no oil reserves.

The distribution of endowments is much more uneven for energy than for capital and labour as well, as can be seen in Figure 2. Whereas the fraction of skilled workers and the amount of capital per capita is relatively similar across states, oil reserves differ greatly. A number of east coast states has no oil at all, whereas Alaska and Wyoming are richly blessed with this natural resource. When some industries require large amounts of energy inputs and reserves are concentrated in a few states, energy availability could be an important consideration in firms' location decision. The effect of energy abundance on location can be particularly pronounced for energy carriers that are costly to transport: coal[2] and electricity[3].

The present paper contributes in several respects. To the best of our knowledge, it is the first to consider in detail the relation between energy abundance

[2] See Gerking and Hamilton [2008]

[3] Electricity can be transported across long distances relatively cheaply with the appropriate infrastructure, but the U.S. electricity grid is not designed to handle large volumes of interregional traffic [Blumsack et al., 2006]

and industry location on the regional level. By focussing on U.S. states, we benefit from the homogeneity in technology and consumer tastes across regions, which magnifies the influence of factor endowments on specialization. At the same time, our primary interest in energy makes the interpretation of results less prone to endogeneity in the distribution of capital and labour across states. The availability of detailed data on energy reserves allows us to insulate effects for four different endowments (coal, natural gas, oil and hydro). We find that all of these energy carriers attract energy-intensive industries; the results are particularly robust for coal and natural gas. A one standard deviation increase in per capita energy endowments increases the activity of energy-intensive industries by about 20%. The rest of this paper is organized as follows. We outline the methodology in section 2. Section 3 gives an overview of the data. We present the results in section 4, and section 5 concludes.

1.2 Industry Location

Leontief [1954] cast the first doubts about the empirical validity of the H-O model. He found that the United States, despite being a capital-abundant country, mainly exported labour-intensive goods. A number of studies in the eighties [Maskus, 1985, Bowen et al., 1987, Brecher and Choudri, 1988] found no relation between factor endowments and the factor content of trade. Bowen et al. conclude that "the Heckscher-Ohlin model does poorly, but we do not have anything better". Trefler [1995] finds that observed trade volumes are lower than predicted by the H-O model. An adapted specification with technology differences and an Armington consumption bias performed much better. Davis et al. [1997] use data on Japanese regions, which exhibit factor price equalization (FPE), and find that the H-O predictions are upheld. Similarly, Davis and Weinstein [2001] report that, when accounting for technology differences and unequal factor prices, countries export their abundant factors. Romalis [2004] looks at the factor content of US trade. The US import more capital- and skill-intensive goods from countries that are abundant in those factors.

At a higher level of regional integration, a number of papers study industry location within EU countries. In addition to factor endowments, this literature typically also considers agglomeration effects [Krugman, 1991]. Economic geography theory posits that the most important determinants of industry location are conventional economies of scale (causing production to be concentrated in a small number of plants) and external economies (causing these plants to locate in the same area). Davis and Weinstein [1999] argue that agglomeration is more pronounced in integrated regions, as higher factor mobility makes it more feasible and lower transport costs more profitable. Amiti [1999] studied specialization in 5 European countries between 1968 and 1990. She concluded that specialization increased over time and finds more evidence for economic geography than for H-O effects, though the insignificance of the H-O variables may be caused by the similar factor endowments of the countries included. One of the most comprehensive studies on European industry location is [Midelfart-Knarvik et al., 2000]. Studying 13 EU countries and 36 industries, they obtain support for both traditional trade theories (captured by interaction terms between country factor endowments and sectoral factor intensities) and economic geography. Using a similar methodology, Mulatu et al. [2010] report that environmental regulation affects the location of pollution-intensive industries, though they find no role for external economies or increasing returns.

Kim [1995] was one of the first to analyze industry location on the regional level. Kim's results indicate that factor abundance and scale economies are a significant driver for regional specialization within the US, but external economies less so. The importance of factor endowments gradually declined over time as factors became more mobile [Kim, 1999]. Redding and Vera-Martin [2006] test the H-O model for 45 European NUTS-1 regions and find that factor endowments can explain industry location on the regional level, though better so for aggregate industries (manufacturing, services, agriculture) than for individual manufacturing sectors. Papers that focus on regions within individual countries include Crafts and Mulatu [2005] (UK) and Paluzie et al. [2001], Requena et al. [2008] (Spain). Using regional data circumvents the problems of different technologies and consumer tastes that plague cross-country studies, but if factors are mobile between regions it may no longer be clear whether factor abundance drives industry location or the other way around [Schott, 2003].

2 Methodology

The three main theories of industry location are Ricardo's theory of comparative advantage, the Heckscher-Ohlin model of factor endowments and the new economic geography literature which emphasizes increasing returns and external economies. While we are foremostly interested in testing whether the H-O predictions hold for energy carriers, we will control for explanations given by the other two theories. Our paper is closely related methodologically to Midelfart-Knarvik et al. [2000], Romalis [2004] and Gerlagh and Mathys [2010]. In their report on industry location in the EU, Midelfart-Knarvik et al. [2000] proposed to interact regional characteristics with sectoral characteristics. If region i has a certain desirable characteristic j, say an abundance of capital, that could make all industries interested in locating in region i. However, the capacity of regions to absorb industries is bounded. Given this, the industries that will end up in region i are those that benefit most from the capital abundance in that region, i.e. capital-intensive sectors. Capital-extensive sectors then have to locate somewhere else and will thus be underrepresented in region i.

This approach can be applied to production factors, as in the example above, as well as economic geography effects. We include two of these. Firstly, industries that are heavily reliant on intermediate inputs may locate near large markets, in which these inputs are more readily available. We control for this by interacting regional market potential with sectoral intermediate goods intensity. Secondly, industries with large economies of scale may locate in central locations. We capture this by interacting market potential with average plant size.[4] Additionally, we use two-way fixed effects for (state,year) and (sector,year).[5] The (state,year) fixed effects control for any changes in state characteristics that affect all sectors, which may include changes in the tax code or labour regulation. The (sector,year) fixed effects control for any unobserved nationwide sectoral trends, such as price changes for crucial inputs or changes in consumer tastes. We omit (sector,state) fixed effects as energy reserves and sectoral energy intensities, which enter into the interaction effects of interest, do not vary much over time.

We measure industrial activity by value added. The notation employed is shown in Table 1. We estimate industry location as dependent on a set of H-O interaction terms, two economic geography interaction terms and control variables. The equation to be estimated is

$$\ln VA_{i,s,t} = \alpha_{i,t} + \beta_{s,t} + \sum_j \gamma_j \pi_{j,s} \theta_{j,i,t} + \sum_k \delta_k \sigma_{k,s} \chi_{i,t} + \eta X_{i,t} + \epsilon_{i,s,t} \quad (1)$$

[4]Other papers also interact market potential with sales to industry, but we lack data on forward linkages.

[5]Midelfart-Knarvik et al. [2000] include cutoff levels for state endowments and sectoral intensities in the interaction terms. The interpretation of an endowment cutoff for skilled labour is the endowment level such that industry location does not depend on the skilled labour intensity of an industry. Analogously, the skilled labour intensity cutoff signals the intensity such that industries do not consider the state endowment of skilled labour when making their location decision. However, since we include fixed effects we cannot identify these cutoffs.

Table 1: Nomenclature

i	state subscript
s	sector subscript
t	time subscript
j	production factor subscript
k	economic geography subscript
$VA_{i,s,t}$	value added
$\pi_{j,s}$	sectoral factor intensities
$\theta_{j,i,t}$	state factor endowments
$\sigma_{k,s}$	sectoral economic geography characteristic
$\chi_{i,t}$	state market potential
$X_{i,t}$	control variables

The Heckscher-Ohlin model predicts that the coefficients on the factor interaction terms γ_j will be positive; economic geography posits that the δ_k coefficients are positive.

3 Data

We use state-level US panel data containing information on energy reserves, sectoral output and factor inputs, covering a period of 2002-2008. The rich energy data allows us to determine the effect of energy abundance on activity in energy-intensive industries for four important energy endowments: natural gas, coal, oil and hydro. For the fossil fuels we define energy abundance per state as proved reserves per capita. For hydro, we use electricity generating capacity per capita. The location of hydropower generation capacity is constrained by geographic characteristics, so we regard hydropower capacity as an adequate proxy for the endowment of suitable hydropower generation locations. The location of nuclear power plants is likely endogenous, so this electricity source is not included in the econometric analysis. For ease of interpretation, we normalize all energy endowments by standard devations. An overview of the distribution of energy endowments across the US is provided in Appendix A.2.

The Manufacturing Energy Consumption Survey (MECS) has sectoral energy intensities for five energy types: electricity, coal, natural gas, distillate fuel oil and residual fuel oil. These energy intensities are available for 3-digit

Table 2: State Characteristics

Variable	Definition	Source
Skilled labour endowment	Fraction of population with a Bachelor's degree or higher	US Census Bureau
Capital endowment	State effect in (3)	Annual Survey of Manufactures
Coal endowment[d]	Estimated recoverable coal reserves per capita, 1000 short tons	Energy Information Administration
Natural gas endowment[d]	Dry natural gas reserves per capita, mln cubic feet	Energy Information Administration
Oil endowment[d]	Crude oil reserves per capita, 1000 barrels[b]	Energy Information Administration
Hydro endowment[d]	Summer capacity hydroelectric generation per capita, Kilowatt	Energy Information Administration
Market potential	$\sum_{i'} \left(\frac{\text{population in state } i' \text{ in } 100.000}{\max\left(\text{distance between states } i \text{ and } i' \text{ in miles}^c, 100\right)} \right)$	US Census Bureau

[a] All endowments are truncated at the 95th percentile.

[b] Does not include Federal Offshore Reserves

[c] We follow [Harris, 1954]. Distances are for the quickest route between the largest cities (2000) in both states (Source: www.mileage-charts.com). The cities are listed in Appendix A.3. Distances to and from Burlington, VT and Honolulu, HI are from Google Maps.

[d] Energy endowments are divided by the standard deviation of state endowments in each year.

Table 3: Sector Characteristics

Variable	Definition	Source
Skilled labour intensity	Nationwide average wage per employee in 2002, USD1000	Annual Survey of Manufactures
Capital intensity	Sector effect in (3)	Annual Survey of Manufactures
Scale economies	Nationwide average plant size in 2002	Economic Census
Intermediate goods intensity	Cost of materials as fraction of value added in 2002	Economic Census
	Specification 1	
Electricity intensity	Quantity of electricy purchased per employee in 2002, 10kwH	Economic Census
Fuel intensity	Cost of purchased fuel per employee in 2002, USD1000	Economic Census
	Specification 2	
Electricity intensity	Electricity use per employee in 2002, bln Btu	Manufacturing Energy Consumption Survey
Natural gas intensity	Natural gas use per employee in 2002, bln Btu	Manufacturing Energy Consumption Survey
Distillate fuel oil intensity	Distillate fuel oil use per employee in 2002, bln Btu	Manufacturing Energy Consumption Survey
Residual fuel oil intensity	Residual fuel oil use per employee in 2002, bln Btu	Manufacturing Energy Consumption Survey

[a] All monetary values scaled to 1984 USD

[b] All intensities are truncated at the 95th percentile.

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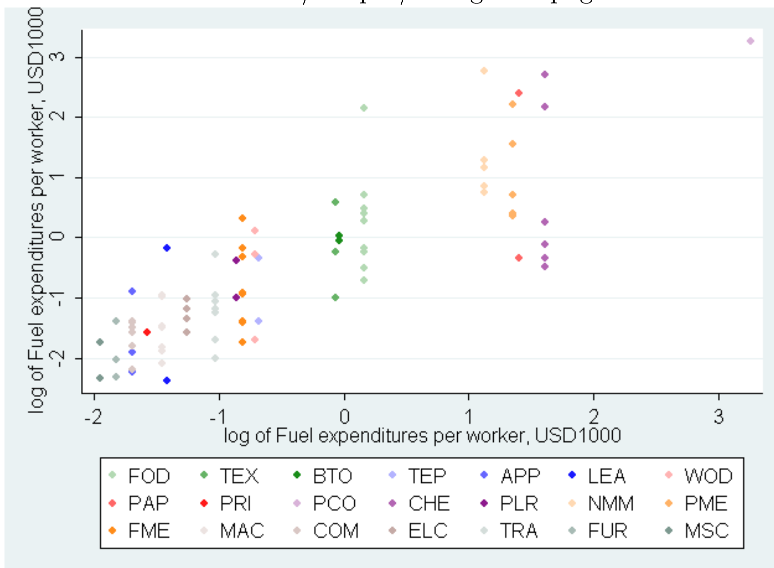

Figure 3: Fuel intensities of 3- and 4-digit NAICS sectors (Source: Economic Census)

NAICS sectors, which are listed in Table 8. The Annual Survey of Manufactures measures energy intensities at a higher level of aggregation: the quantity of electricity purchased and the cost of purchased fuels. In contrast to the MECS, these statistics are also available for 4-digit NAICS sectors. The distinction is potentially important as factor intensities of 4-digit sectors can differ substantially from those of the aggregate 3-digit sector. Schott [2003] gives the example of the three-digit ISIC sector Electrical Machinery, which contains both portable radios assembled by hand and capital-intensive satellites.

Figures 3 and 4 give an indication of the variation in energy intensities between and within 3-digit NAICS sectors. Horizontal distances indicate variation between 3-digit sectors; the vertical axis measures the energy intensity of 4-digit sectors. All 4-digit sectors within the same 3-digit sector are in one column and of the same colour. The axes are scaled logarithmically. The figures show a substantial variation within 3-digit sectors, also within energy-intensive ones such as Paper, Chemicals and Primary Metals.

In Figures 5 and 6 we show the relation between the aggregate fuel intensity measure of the Economic Census and the more disaggregated natural gas and distillate fuel oil intensities from the MECS. The axes are again scaled logarith-

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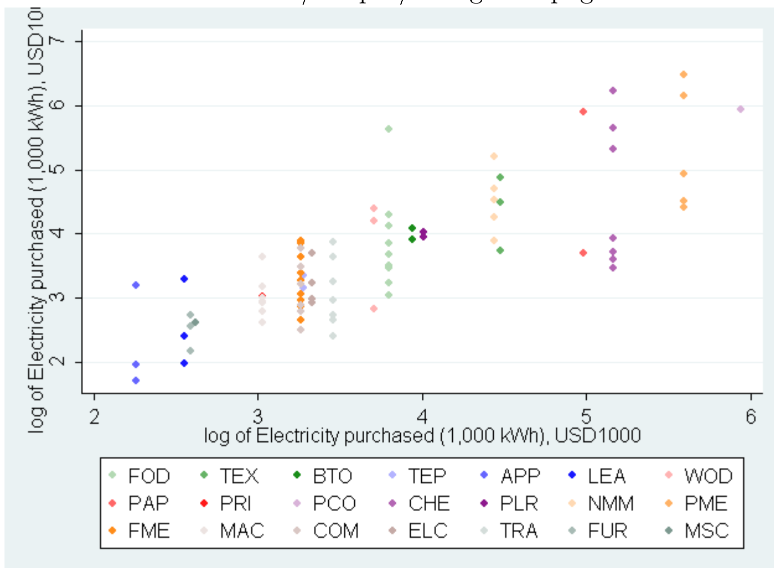

Figure 4: Electricity intensities of 3- and 4-digit NAICS sectors (Source: Economic Census)

mically. Fuel intensity is almost a perfect indicator of natural gas intensity, as can be seen in Figure 5. For distillate fuel oil the relation is somewhat weaker, but still quite strong.

The variation in electricity and fuel intensities within 3-digit NAICS sectors is larger than the variation in intensities of different fuel types. We will therefore use the Economic Census energy intensities for our preferred specification, and the MECS intensities for a robustness check. We also normalize the energy intensities. In one set of specifications, we discretize the energy intensities such that they are equal to one (zero) if the sector consumes more (less) of the energy type than average. In a second set of specifications, we normalize the intensities such that they have mean $\frac{1}{2}$ and standard deviation $\frac{1}{2}$. The electricity-intensity is then equal to one for the typical electricity-intensive sector, and equal to zero for the typical electricity-extensive sector. A complete overview of the variables included in the interaction terms is given in Tables 2 (state characteristics) and 3 (sector characteristics).

Value added shares for the disaggregated energy types are displayed in Figure 7. The average fractions of value added spent on natural gas and electricity are substantial: 2.7% and 2.5% respectively, whereas for coal and distillate fuel

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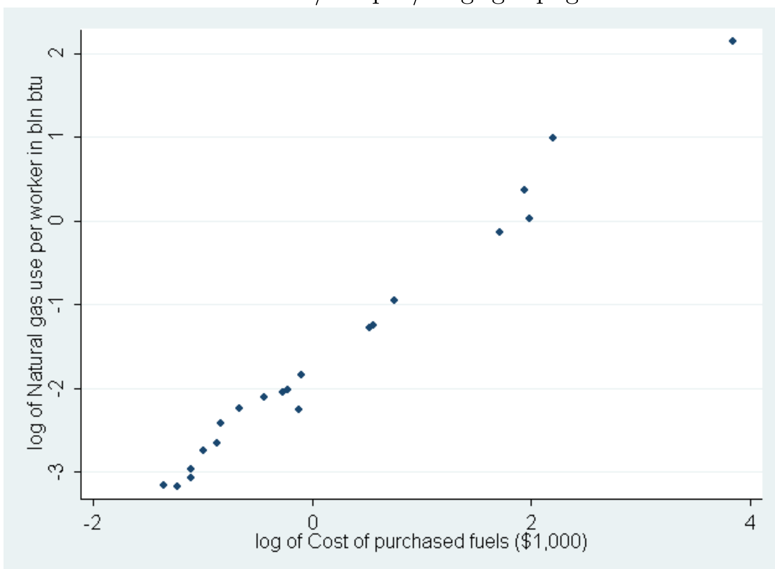

Figure 5: Fuel intensities (Economic Census) and Natural gas intensities (MECS) of 3-digit NAICS sectors

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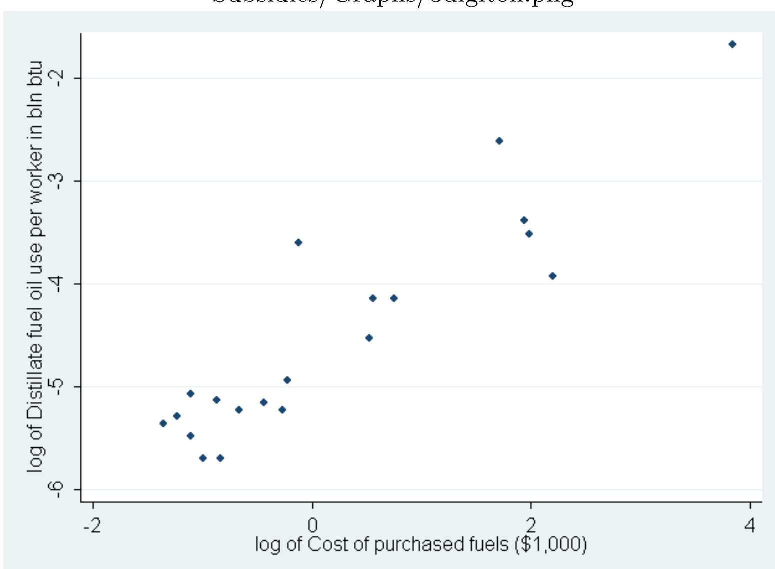

Figure 6: Fuel intensities (Economic Census) and Distillate fuel oil intensities (MECS) of 3-digit NAICS sectors

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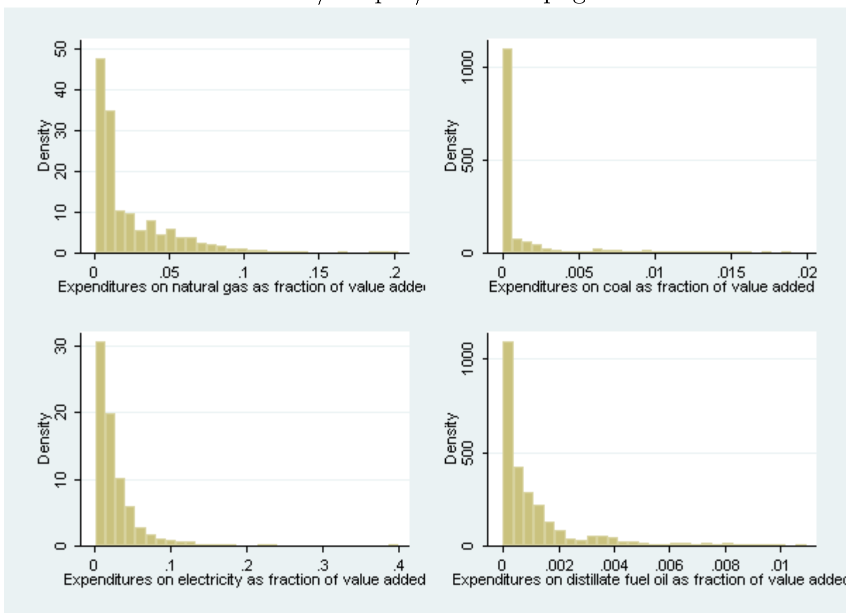

Figure 7: Fraction of value added spent per energy type in 2005

oil the averages are quite modest (slightly in excess of 0.1%). These differences may explain why the correlation between natural gas intensity and aggregate fuel intensity (Figure 5) is larer than between distillate fuel oil intensity and aggregate fuel intensity (Figure 6).

The sources of electricity generation in the US are depicted in Figure 8. When constructing the H-O interaction variables for energy, we opt to interact coal abundance with electricity intensity rather than coal intensity: coal inputs account for almost 50% of electricity generation in the US and because the value added share of electricty is much greater than that of coal, electricity intensity will play a larger role in industry location than coal intensity. Additionally, we introduce [hydropower capacity $\times$ electricity intensity] and [natural gas abundance $\times$ electricity abundance] interaction terms for determining the location of electricity-intensive industries.

Capital is measured by capital investments. We assume that the economy is in steady state, so that unobserved capital stocks are proportional to investments. Unlike for energy, we do not have data on state capital endowments. To assess the role of capital, we can however construct proxies for endowments and intensities. We follow Gerlagh and Mathys [2010] in decomposing the ratio

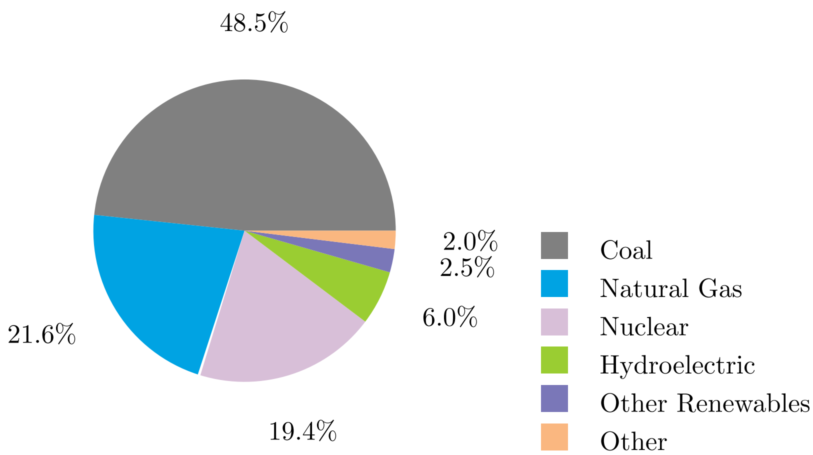

Figure 8: Electricity generation in the US by source in 2007 (EIA)

of capital ($K_{s,i}$) to labour ($L_{s,i}$) employment in each sector into a state- and a sector-specific term. Cost minimization given a Cobb-Douglas production function, letting $\xi_{j,s}$ denote the intensity of factor j in industry s, mandates

$$\frac{K_{s,i}}{L_{s,i}} = \frac{\xi_{K,s} w_i}{\xi_{L,s} r_i}$$

Take logs on both sides

$$\ln \frac{K_{s,i}}{L_{s,i}} = \ln \frac{\xi_{K,s}}{\xi_{L,s}} - \ln \frac{r_i}{w_i} \tag{2}$$

If the left hand hand side of (2) is observed, the right hand side can be estimated by regressing the capital-labour employment ratios on a set of sector- and region-dummies. We assume that production technologies do not change during our sample period, thus holding the sector-specific term constant over time.[6] The equation to be estimated is then

$$\ln \frac{K_{s,i,t}}{L_{s,i,t}} = \hat{\pi}_{K,s} + \hat{\theta}_{K,i,t} + \epsilon_{s,i,t} \tag{3}$$

The under/overuse of capital relative to labour in state i that is now indicated by $\hat{\theta}_{K,i,t}$ depends on the relative price of capital and labour. The price ratio may either be either be driven by capital abundance (as in Romalis [2004]) or by price-distorting public policies; this is irrelevant for our purposes.

[6] Our measure of capital is capital expenditures, which depend on the interest rate. Therefore, it is important that the state-specific effects are allowed to vary over time.

In the set of control variables X we include interactions of sector dummies with East Coast[7] and West Coast[8] dummies to account for the possibility that exporting industries want to locate in coastal areas. Furthermore, we interact sector dummies with state population densities, as some industries might be overrepresented in densely or scarcely populated regions. Since the economic geography interaction terms are correlated with these control variables, the coefficients should be interpreted with care.

4 Results

The results for our preferred dataset, with disaggregated sector information, are presented in Table 4. In first four columns, the energy intensities are dummy variables. In the last four columns, they are normalized to a mean of $\frac{1}{2}$ and a standard deviation of $\frac{1}{2}$. The effect of energy endowments on industry location is highly significant; both statistically and economically. The location of electricity-intensive industries depends on coal, hydro and natural gas endowments. A one standard deviation increase in per capita coal, natural gas or hydro endowments increases the value-added of sectors that are more electricity-intensive than average by about 20%. In individual regressions, both natural gas and oil endowments significantly affect the activity of fuel-intensive sectors. A one standard deviation increase in per capita natural gas endowments increases the value added of gas-intensive industries by 25%. The effect is more robust for natural gas than for oil, which might be explained by the high correlation between natural gas and fuel intensities (Figure 5) and the higher value added share of natural gas in manufacturing (Figure 7). We also find that skilled labour is an important determinant of industry location. The interaction terms for capital and economic geography are insignificant; the latter even have a negative sign. The results in column (5)-(8) are more accurate, since the continuous energy intensities provide more information than the discretized ones. Their interpretation is a bit more ambiguous however. The coefficients on the energy interaction terms can be interpreted as the percentage change in value added of a typical energy-intensive sector as a result of a one standard deviation increase in per capita endowments. Qualitatively, the results are almost the same as in the first columns.

[7] East Coast states: Maine, New Hampshire, Rhode Island, Connecticut, New York, New Jersey, Delaware, Maryland, Virginia, North Carolina, South Carolina, Georgia, Florida

[8] West Coast states: California, Washington, Oregon, Hawaii, Alaksa

Table 4: Location of 4-digit NAICS sectors, dependent variable: $\ln VA$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
electricity intensity × coal abundance	0.19				0.18			
	(0.057)***				(0.045)***			
electricity intensity × natural gas abundance	0.14				0.22			
	(0.064)**				(0.070)***			
electricity intensity × hydropower capacity	0.24				0.16			
	(0.047)***				(0.043)***			
fuel intensity × natural gas abundance		0.25		0.23		0.25		0.22
		(0.065)***		(0.078)***		(0.075)***		(0.101)**
fuel intensity × oil abundance			0.25	0.04			0.24	0.04
			(0.086)***	(0.103)			(0.0090)***	(0.122)
capital intensity × capital abundance	0.03	-0.10	-0.12	-0.10	0.08	-0.09	-0.12	-0.09
	(0.152)	(0.152)	(0.149)	(0.151)	(0.154)	(0.155)	(0.150)	(0.154)
skill intensity × skill abundance	0.20	0.22	0.21	0.22	0.22	0.21	0.21	0.21
	(0.100)**	(0.098)**	(0.098)**	(0.098)**	(0.100)**	(0.098)**	(0.098)**	(0.098)**
intermediate goods intensity × market potential	-0.03	-0.04	-0.04	-0.04	-0.02	-0.03	-0.04	-0.03
	(0.022)	(0.023)*	(0.022)**	(0.023)*	(0.023)	(0.023)	(0.022)*	(0.023)
plant size × market potential	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
energy intensities[b]	discrete	discrete	discrete	discrete	continuous	continuous	continuous	continuous
N	14538.00	14925.00	14925.00	14925.00	14538	14925	14925	14925
N_clust	2939.00	3036.00	3036.00	3036.00	2939	3036	3036	3036
R^2 adjusted	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65

[a] Notes: independent variables listed in first row. Two-way fixed effects (state,year and sector,year) are included, as well as geography controls (east coast and west coast dummies and population density; these are all interacted with a full set of sector dummies). Error terms are clustered by state,year. Standard errors in parentheses. Asterixes denote significance at 10% (*), 5% (**) and 1% (***)

[b] Discrete: the intensity is equal to one if it is larger than average, and zero if it is smaller than average. Continuous: the intensities are normalized such that they have mean $\frac{1}{2}$ and standard deviation $\frac{1}{2}$

We also test an alternative specification with the log of employment, rather than value added, as dependent variable, since the effect of factor prices on value added is potentially ambiguous. Higher factor prices lead to lower output [Romalis, 2004], but since value added depends on prices times output, value added measures might misrepresent economic activity [Gerlagh and Mathys, 2010]. The results are shown in Table 5. The results remain largely the same, though the coefficients on the energy interaction terms are slightly lower in absolute value. A one standard deviation increase in per capita coal endowments increases employment in electricity-intensive sectors by 17%. The skill coefficient becomes more significant, which is not surprising given that the endogeneity problem for this variable is more pronounced with employment as dependent variable than with value added: value added encompasses returns to all factors, whereas [labour] employment only includes skilled and unskilled labour. Labour employment levels will therefore more strongly drive interstate skilled labour relocation than value added. However, the skilled labour interaction term is not our variable of interest; we merely use it as a control variable. Hence the skilled labour coefficient might not measure the true marginal effect of the interaction term, but it can still control for possible omitted variable bias.

The robustness check with disaggregated energy intensities is presented in Table 6. We again find significant effects for coal and natural gas, which are in the same order of magnitude as in the regressions with the 4-digit sector data. The hydropower interaction term is no longer significant however, even though the U.S. electricity market is highly segregated. In the joint estimation, our model loses some explantary power and the residual fuel oil interaction term is no longer significant, but effects for coal and natural gas persist. Compared to the results in Table 4, it is noteworthy that the skill interaction term is not significant, whereas the [plant size $\times$ market potential] term has changed sign and is different from zero at the 1% level.

Table 7 reports the estimates for the MECS energy intensity data with the log of employment as the dependent variable. Similar to the Economic Census data, using employment rather than value added does not fundamentally change the results. In regression (2) however, natural gas endowments are no longer significant whereas coal endowments play a larger role, being significant at the 1% level. As in Table 5, the effect of skilled labour is stronger when using employment as dependent variable.

Table 5: Location of 4-digit NAICS sectors, dependent variable: $\ln L$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
electricity intensity × coal abundance	0.17				0.16			
	(0.049)***				(0.041)***			
electricity intensity × natural gas	0.10				0.13			
abundance	(0.048)**				(0.048)***			
electricity intensity × hydropower	0.21				0.14			
capacity	(0.041)***				(0.038)***			
fuel intensity × natural gas abundance		0.18		0.15		0.16		0.12
		(0.048)***		(0.060)**		(0.050)***		(0.067)*
fuel intensity × oil abundance			0.19	0.05			0.18	0.08
			(0.064)***	(0.080)			(0.061)***	(0.081)
capital intensity × capital abundance	-0.01	-0.13	-0.15	-0.14	0.02	-0.13	-0.15	-0.14
	(0.117)	(0.115)	(0.113)	(0.114)	(0.115)	(0.115)	(0.112)	(0.114)
skill intensity × skill abundance	0.22	0.23	0.23	0.23	0.24	0.23	0.23	0.23
	(0.083)***	(0.082)***	(0.081)***	(0.082)***	(0.083)***	(0.082)***	(0.081)***	(0.082)***
intermediate goods intensity × market	-0.01	-0.01	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01
potential	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
plant size × market potential	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
energy intensities	discrete	discrete	discrete	discrete	continuous	continuous	continuous	continuous
N	15364.00	15788	15788	15788	15364	15788	15788	15788
N_clust	3089	3189	3189	3189	3089	3189	3189	3189
R^2 adjusted	0.70	0.69	0.69	0.69	0.70	0.69	0.69	0.69

[a] Notes: independent variables listed in first row. Two-way fixed effects (state,year and sector,year) are included, as well as geography controls (east coast and west coast dummies and population density; these are all interacted with a full set of sector dummies). Error terms are clustered by state,year. Standard errors in parentheses. Asterixes denote significance at 10% (*), 5% (**) and 1% (***)

[b] Discrete: the intensity is equal to one if it is larger than average, and zero if it is smaller than average. Continuous: the intensities are normalized such that they have mean $\frac{1}{2}$ and standard deviation $\frac{1}{2}$

Table 6: Industry location with disaggregated energy intensities, dependent variable: $\ln VA$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
gas intensity × natural gas abundance	0.25			0.18	0.28			0.11
	(0.077)***			(0.086)**	(0.078)***			(0.098)
electricity intensity × coal abundance		0.22		0.20		0.23		0.15
		(0.088)**		(0.090)**		(0.079)***		(0.093)
electricity intensity × hydropower capacity		0.05		0.05		0.07		0.10
		(0.069)		(0.069)		(0.079)		(0.078)
electricity intensity × natural gas abundance		0.19				0.21		
		(0.078)**				(0.088)**		
distillate fuel oil intensity × oil abundance			0.16	0.03			0.31	0.27
			(0.079)**	(0.093)			(0.093)***	(0.091)***
residual fuel oil intensity × oil abundance			0.15	0.05			0.24	0.13
			(0.109)	(0.099)			(0.133)*	(0.148)
capital intensity × capital abundance	0.22	0.27	0.23	0.27	0.22	0.26	0.28	0.36
	(0.169)	(0.169)	(0.169)	(0.169)	(0.168)	(0.168)	(0.188)	(0.189)*
skill intensity × skill abundance	0.20	0.18	0.22	0.18	0.19	0.19	0.22	0.19
	(0.152)	(0.156)	(0.149)	(0.156)	(0.152)	(0.157)	(0.152)	(0.160)
intermediate goods intensity × market potential	-0.06	-0.06	-0.06	-0.06	-0.05	-0.04	-0.03	-0.02
	(0.029)**	(0.029)**	(0.029)**	(0.029)*	(0.029)*	(0.029)	(0.027)	(0.029)
plant size × market potential	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0.001)***	(0.001)**	(0.001)**	(0.001)**	(0.001)***	(0.001)***	(0.001)**	(0.001)**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
energy intensities[b]	discrete	discrete	discrete	discrete	continuous	continuous	continuous	continuous
N	6580.00	6345	6580	6345	6580	6345	5946	5736
N_clust	968	931	968	931	968	931	874	841
R^2 adjusted	0.78	0.78	0.78	0.78	0.78	0.79	0.77	0.77

[a] Notes: independent variables listed in first row. Two-way fixed effects (state,year and sector,year) are included, as well as geography controls (east coast and west coast dummies and population density; these are all interacted with a full set of sector dummies). Error terms are clustered by state,year. Standard errors in parentheses. Asterixes denote significance at 10% (*), 5% (**) and 1% (***)

[b] Discrete: the intensity is equal to one if it is larger than average, and zero if it is smaller than average. Continuous: the intensities are normalized such that they have mean $\frac{1}{2}$ and standard deviation $\frac{1}{2}$

Table 7: Industry location with disaggregated energy intensities, dependent variable: $\ln L$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
gas intensity × natural gas abundance	0.17			0.28	0.19			0.20
	(0.062)***			(0.276)	(0.068)***			(0.138)
electricity intensity × coal abundance		0.21		0.21		0.21		0.15
		(0.077)***		(0.079)***		(0.069)***		(0.077)*
electricity intensity × hydropower capacity		0.03		0.03		0.04		0.05
		(0.056)		(0.056)		(0.062)		(0.064)
electricity intensity × natural gas abundance		0.11		-0.17		0.11		-0.19
		(0.064)*		(0.270)		(0.071)		(0.112)*
distillate fuel oil intensity × oil abundance			0.13	0.02			0.25	0.24
			(0.059)**	(0.070)			(0.072)***	(0.075)***
residual fuel oil intensity × oil abundance			0.10	0.02			0.16	0.06
			(0.087)	(0.078)			(0.102)	(0.114)
capital intensity × capital abundance	0.14	0.16	0.14	0.16	0.14	0.16	0.16	0.21
	(0.129)	(0.131)	(0.129)	(0.131)	(0.128)	(0.130)	(0.140)	(0.143)
skill intensity × skill abundance	0.33	0.32	0.34	0.32	0.32	0.33	0.34	0.32
	(0.125)***	(0.125)**	(0.123)***	(0.125)**	(0.125)**	(0.126)***	(0.126)***	(0.130)**
intermediate goods intensity × market potential	-0.02	-0.03	-0.02	-0.03	-0.02	-0.02	0.00	-0.01
	(0.023)	(0.022)	(0.023)	(0.021)	(0.023)	(0.021)	(0.021)	(0.021)
plant size × market potential	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0.001)***	(0.001)***	(0.001)***	(0.001)***	(0.001)***	(0.001)***	(0.001)***	(0.001)***
energy intensities[b]	discrete	discrete	discrete	discrete	continuous	continuous	continuous	continuous
N	6810	6552	6810	6552	6810	6552	6147	5917
N_clust	990	952	990	952	990	952	893	859
R^2 adjusted	0.82	0.83	0.82	0.83	0.82	0.83	0.81	0.82

[a] Notes: independent variables listed in first row. Two-way fixed effects (state,year and sector,year) are included, as well as geography controls (east coast and west coast dummies and population density; these are all interacted with a full set of sector dummies). Error terms are clustered by state,year. Standard errors in parentheses. Asterixes denote significance at 10% (*), 5% (**) and 1% (***)

[b] Discrete: the intensity is equal to one if it is larger than average, and zero if it is smaller than average. Continuous: the intensities are normalized such that they have mean $\frac{1}{2}$ and standard deviation $\frac{1}{2}$

5 Conclusion

Though energy is often overlooked in industry location analyses, it plays a large role in the distribution of manufacturing sectors in the US. The large variation in sectoral intensities and state endowments make it an important determinant of industrial activity. The effects are particularly strong for coal and natural gas. Both of these energy carriers constitute a large share of value added in manufacturing, and transport costs for coal are relatively high. A one standard deviation increase in coal or natural gas endowments increases the activity of energy-intensive industries by 20-25%, which is an economically very significant effect. The effects are robust to different measures of industrial activity (value added or employment) and to different aggregation levels of sectors and energy intensities.

Oil and hydro endowments seem to have a positive influence on the location of energy- intensive industries, but are not siginificant in all specifications. Clarifying the role of these endowments is an potential avenue for further research. Interestingly, we find no effect of capital endowments and intensities. This may partly be explained by difficulties in measuring state or national capital endowments. However, the variation in capital intensities and endowments is much smaller than the variation in energy intensities and endowments. This suggests that energy may play at least as large a role as capital in industry location decisions. Our results cast doubt on the usual practice of including capital but not energy in industry location studies.

Our findings may also have implications for environmental policy. If energy-intensive industries benefit from locating close to energy reserves, this reduces their incentive to relocate in the face of environmental regulation. Energy-abundant states may be able to set more stringent environmental policy, without needing to fear that they will lose energy-intensive industries.

A Appendix

A.1 Industries

A.2 Energy Endowments

In this section, we present an overview of energy reserves and electricity generation per state.

NAICS code	Abbreviation	Description
311	FOD	Food
312	BTO	Beverage & Tobacco Products
313	TEX	Textile Mills
314	TEP	Textile Product Mills
315	APP	Apparel
316	LEA	Leather and Allied Products
321	WOD	Wood Products
322	PAP	Paper
323	PRI	Printing & Related Support Activities
324	PCO	Petroleum & Coal Products
325	CHE	Chemicals
326	PLR	Plastics & Rubber Products
327	NMM	Nonmetallic Mineral Products
331	PME	Primary Metals
332	FME	Fabricated Metal Products
333	MAC	Machinery
334	COM	Computers & Electronic Products
335	ELC	Electrical Equipment, Appliances & Components
336	TRA	Transportation Equipment
337	FUR	Furniture & Related Products
339	MSC	Miscellaneous Manufacturing

Table 8: Industries included in Table 6 and 7 regressions

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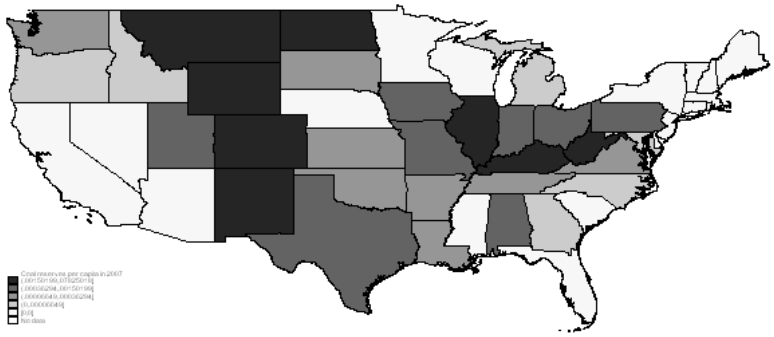

Figure 9: Coal reserves at producing mines per capita, mln short tons

A.2.1 Energy reserves

Coal reserves are depicted in Figure 9. There are two main coal producing regions in the US: the Appalachians (with Illinois, Kentucky and West Virginia as the most coal abundant states) and the Mid-West (with large reserves in Wyoming, North Dakota and Montana). By far the most coal reserves are located in Wyoming: it has over one third of total coal reserves in the US, and 14 times more reserves per capita than the national average.

Natural gas reserves are shown in Figure 10. Most gas reserves in the lower 48 states are in the Rocky Mountains and the south of the country. Texas has over a quarter of total US reserves; Wyoming, Oklahoma and Colorado around ten percent each. On a per capita level, Wyoming is by far the most abundant (12 times more per capita reserves than the national average), followed by Alaska (2.5 times the national average), New Mexico and Oklahoma.

Figure 11 gives an overview of oil reserves. The three most important oil reserves are in Texas, California and Alaska. Correcting for population, Alaska stands out with 14 times as many oil reserves per capita than the national average, followed by Wyoming and North Dakota.

A.2.2 Electricity generation

We show electricity generation per state in Figures 12, 13 and 14. Coal, natural gas and hydropower are three of the four most important sources of electricity generation in the US (see Figure 8). We disregard nuclear power because the location of nuclear plants may be endogenous.

Comparing the location of coal-based electricity generation with the coal

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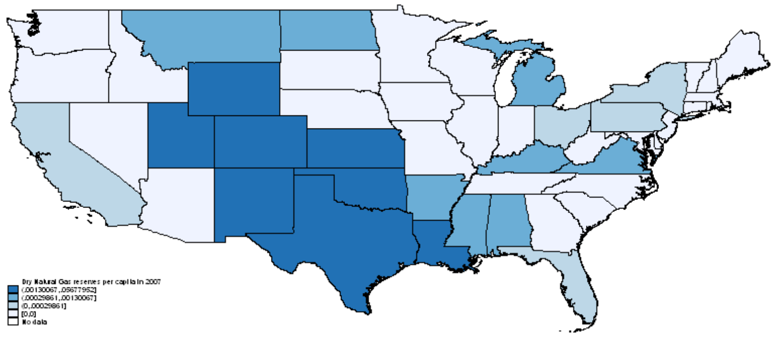

Figure 10: Dry natural gas reserves per capita, bln cubic feet

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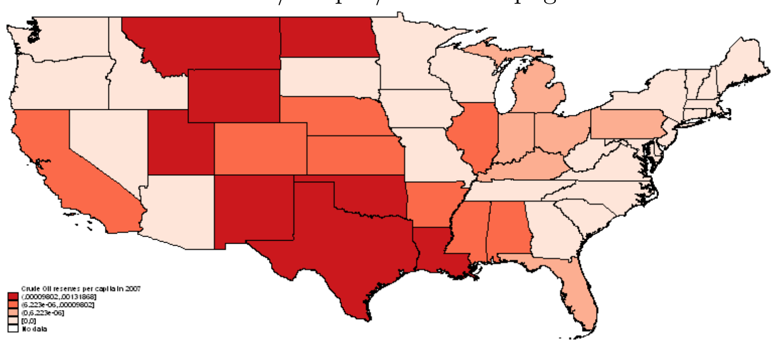

Figure 11: Crude oil reserves per capita, mln barrels

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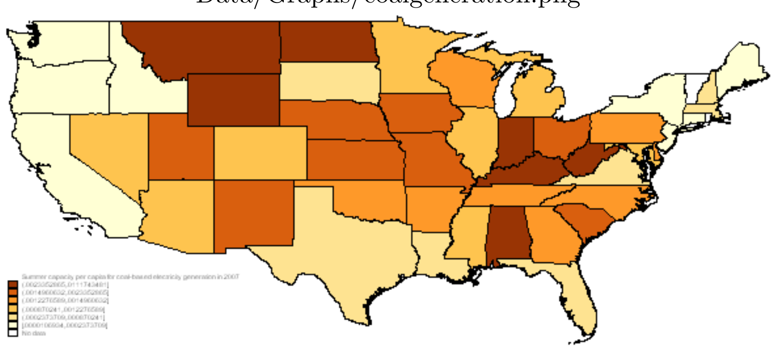

Figure 12: Coal-based electricity generation summer capacity per capita in 2007, Megawatt

Data/Graphs/gasgeneration.png

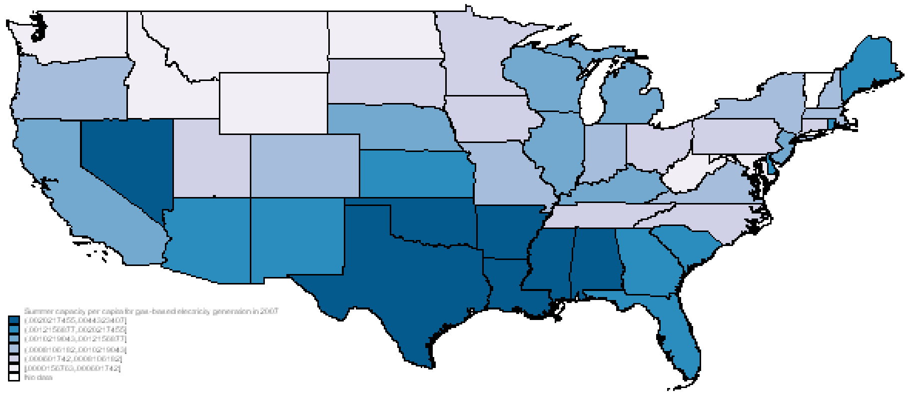

Figure 13: Natural Gas-based electricity generation summer capacity per capita in 2007, Megawatt

reserves in Figure 9, there are strong similarities. Coal-based electricity generation happens largely in states that also have large coal reserves. In 2007, the correlation coefficient between coal-based electricity generation per capity and coal reserves per capita was 0.775. For natural gas, there is no such relation however. Comparing Figures 10 and 13, some abundant states have relatively little gas-based electricity generation (Wyoming, Montana, Utah, Colorado), whereas southeastern states (Georgia, Florida and Mississippi among others) have more gas-based electricity generation capacity than one might expect on the basis of their gas reserves. The corresponding correlation coefficient was -0.094 in 2007. We conjecture that the different patterns for coal and gas have to do with the relatively high transport costs for coal compared to gas.

Lastly, hydroelectric electricity generation is shown in Figure 14. Opportunities for hydroelectric electricity generation depend largely on the physical characteristics of a state. Due to their rugged terrain, Northwestern states most readily lend themselves for this type of electricity generation.

A.3 Largest cities in states

References

M. Amiti. Specialization patterns in europe. Review of World Economics, 135(4):573–593, 1999.

Table 9: Cities used for calculating distances between states

State	City	State	City
Alabama	Birmingham	Montana	Billings
Alaska	Anchorage	Nebraska	Omaha
Arizona	Phoenix	Nevada	Las Vegas
Arkansas	Little Rock	New Hampshire	Manchester
California	Los Angeles	New Jersey	Newark
Colorado	Denver	New Mexico	Albuquerque
Connecticut	Bridgeport	New York	New York
Delaware	Wilmington	North Carolina	Charlotte
Florida	Jacksonville	North Dakota	Fargo
Georgia	Atlanta	Ohio	Columbus
Hawaii	Honolulu	Oklahoma	Oklahoma City
Idaho	Boise	Oregon	Portland
Illinois	Chicago	Pennsylvania	Philadelphia
Indiana	Indianapolis	Rhode Island	Providence
Iowa	Des Moines	South Carolina	Columbia
Kansas	Wichita	South Dakota	Sioux Falls
Kentucky	Louisville	Tennessee	Memphis
Louisiana	New Orleans	Texas	Houston
Maine	Portland	Utah	Salt Lake City
Maryland	Baltimore	Vermont	Burlington
Massachusetts	Boston	Virginia	Virginia Beach
Michigan	Detroit	Washington	Seattle
Minnesota	Minneapolis	West Virginia	Charleston
Mississippi	Jackson	Wisconsin	Milwaukee
Missouri	Kansas City	Wyoming	Cheyenne

Data/Graphs/hydrogeneration.png

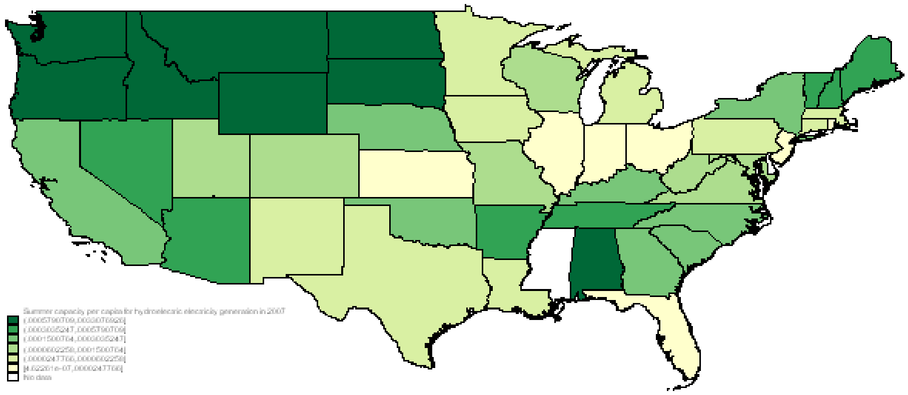

Figure 14: Hydroelectric electricity generation summer capacity per capita in 2007, Megawatt

E. R. Berndt and D. O. Wood. Technology, prices, and the derived demand for energy. Review of Economics and Statistics, 57(3):259–268, 1975.

S. B. Blumsack, J. Apt, and L. B. Lave. Lessons from the failure of u.s. electricity restructuring. Electricity Journal, 19(2):15–32, 2006.

H. P. Bowen, E. E. Leamer, and L. Sveikauskas. Multicountry, multifactor tests of the factor abundance theory. American Economic Review, 77(5):791–809, 1987.

R. A. Brecher and E. U. Choudri. The factor content of consumption in canada and the united states: A two-country test of the heckscher-ohlin-vanek model. In R. C. Feenstra, editor, Empirical methods for international trade. MIT Press, 1988.

N. Crafts and A. Mulatu. What explains the location of industry in britain, 18711931? Journal of Economic Geography, 5(4):499–518, 2005.

D. R. Davis and D. E. Weinstein. Economic geography and regional production structure: An empirical investigation. European Economic Review, 43:379–407, 1999.

D. R. Davis and D. E. Weinstein. An account of global factor trade. American Economic Review, 91(5):1423–1453, 2001.

D. R. Davis, D. E. Weinstein, S. C. Bradford, and K. Shimpo. Using international and japanese regional data to determine whether the factor abundance theory of trade works. American Economic Review, 87(3):421–446, 1997.

G. Ellison and E. L. Glaeser. The geographic concentration of industry: Does natural advantage explain agglomeration? American Economic Review, 89(2):311–316, 1999.

S. Gerking and S. F. Hamilton. What explains the increased utilization of powder river basin coal in electric power generation? American Journal of Agricultural Economics, 90(4):933–950, 2008.

R. Gerlagh and N. A. Mathys. Energy abundance, trade, and industry location, 2010.

C. D. Harris. The market as a factor in the localization of industry in the united states. Annals of the Association of American Geographers, 44(4):315–348, 1954.

A. L. Hillman and C. W. Bullard. Energy, the heckscher-ohlin theorem, and u.s. international trade. American Economic Review, 68(1):96–106, 1978.

S. Kim. Expansion of markets and the geographic distribution of economic activities: The trends in u.s. regional manufacturing structure, 1860-1987. Quarterly Journal of Economics, 110(4):881–908, 1995.

S. Kim. Regions, resources, and economic geography: sources of u.s. regional comparative advantage, 1880-1987. Regional Science and Urban Economics, 29:1–32, 1999.

P. Krugman. Geography and Trade. MIT Press, 1991.

W. Leontief. Domestic production and foreign trade: The american capital position re-examined. Economia Internazionale, 7:3–32, 1954.

K. E. Maskus. A test of the heckscher-ohlin-vanek theorem: The leontief commonplace. Journal of International Economics, 9(3-4):201–212, 1985.

K. Midelfart-Knarvik, H. Overman, and A. Venables. Comparative advantage and economic geography: Estimating the location of production in the eu. CEPR discussion paper no. 2618, 2000.

A. Mulatu, R. Gerlagh, D. Rigby, and A. Wossink. Environmental regulation and industry location in europe. Environmental and Resource Economics, 45: 459–479, 2010.

E. Paluzie, J. Pons, and D. Tirado. Regional integration and specialization patterns in spain. Regional Studies, 4(1):285–296, 2001.

S. Redding and M. Vera-Martin. Factor endowments and production in european regions. Review of World Economics, 142(1):1–32, 2006.

F. Requena, A. Artal, and J. Castillo. Testing heckscher-ohlin-vanek model using spanish regional data. International Regional Science Review, 31(2): 159–184, 2008.

J. Romalis. Factor proportions and the structure of commodity trade. American Economic Review, 94(1):67–97, 2004.

P. K. Schott. One size fits all? heckscher-ohlin specialization in global production. American Economic Review, 93(3):686–708, 2003.

D. Trefler. The case of missing trade and other mysteries. American Economic Review, 85(5):1029–1046, 1995.